STUDIES BASED ON THE COLORS AND MAGNITUDES IN STELLAR CLUSTERS[1]

FOURTEENTH PAPER: FURTHER REMARKS ON THE STRUCTURE OF THE GALACTIC SYSTEM

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The present paper contains miscellaneous notes relating to or extending the results and arguments of the twelfth paper of this series. To economize space the observations are treated synoptically, and the discussion of interpretations is abbreviated in so far as consistent with a fair presentation. The subjects discussed are the following:

I. The indication of a direct relationship between globular and open clusters afforded by the galactic distribution.

II. The seventeen clusters which recent studies have added to the original lists in *Mount Wilson Contribution* No. 152.

III. Diagrams of the positions in space of all globular clusters.

IV. Evidence that the observed absence of globular clusters from the equatorial segment is not due to obstructing cosmic clouds in the Milky Way.

V. The diameter-parallax relation for globular clusters as derived from other sources than the Franklin-Adams charts.

VI. Holetschek's magnitudes of 40 globular clusters and the possibility of determining relative parallaxes from measures of the integrated light.

VII. Observational data supporting the view that the motions and distribution of spiral nebulae depend upon dynamical causes quite different from those prevailing in clusters of stars.

VIII. The bearing of the cluster studies on the formulation of a tentative hypothesis of the origin and development of the galactic system.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 161.

IX. Evidence from the *Henry Draper Catalogue* concerning the extent and inclination of the local cluster defined in *Mount Wilson Contributions*, No. 157.

I. THE COMPLEMENTARY DISTRIBUTION IN GALACTIC LATITUDE OF GLOBULAR AND OPEN CLUSTERS

Although we have not as yet determined individual distances for open clusters we may safely accept that, generally speaking, they are much nearer the sun than the globular systems. If we should assume that the two kinds are similarly distributed with respect to the galactic plane,[1] most open groups would appear in relatively high galactic latitude, because of their proximity to the sun. With the exception of such near and luminous groups as the Pleiades and Praesepe, however, they occur only in low galactic latitudes, and they do not show the avoidance of the Milky Way exhibited by globular clusters. In fact, when actual positions in space are considered, they appear to occur in the dense stellar regions where globular clusters are not found; and they do not occur in the extra-galactic realms where the globular clusters are. This apparently complementary distribution of the two types of clusters is of high importance for the hypothesis which derives the galactic system originally from stellar clusters and obtains the open groups of the Milky Way from the extra-galactic globular organizations.

The continuous gradation of the compact groups into the open clusters of the Milky Way might be more clearly shown if we could correlate compactness with $R \sin \beta$;[2] but lacking parallaxes of the open clusters, we must for the present content ourselves with pointing out the complementary character of the frequencies of galactic latitude. In Fig. 1 the full line refers to open clusters—the objects of Classes II and III of Melotte's catalogue.[3] A few clusters have been withdrawn from his classes and two or three added, on the

[1] Cf. *Contributions from the Mount Wilson Solar Observatory*, No. 152, Figs. 4, 5, and 6; No. 157, Fig. 2.

[2] R is the radial distance from the earth, β is the galactic latitude.

[3] *Memoirs of the Royal Astronomical Society*, **60**, Part V, 1915. Diagrams by Melotte illustrate the well-known difference for open and globular clusters of the distribution in galactic longitude.

basis of Mount Wilson plates. Table I contains the assembled results.

The dotted line in Fig. 1 refers to globular clusters; the data are from *Mount Wilson Contributions*, No. 152,[1] supplemented by the additional material in Table II of this paper, omitting only the five

TABLE I

FREQUENCY IN GALACTIC LATITUDES OF OPEN AND GLOBULAR CLUSTERS

Galactic Latitude	Number of Open Clusters		Number of Globular Clusters	
	North	South	North	South
0°– 2°	21	25	0	0
2 – 4	19	19	1	1
4 – 6	10	13	4	2
6 – 8	7	4	3	5
8 –10	3	7	4	5
10 –12	5	0	4	3
12 –14	4	2	2	3
14 –16	0	3	4	2
16 –18	3	3	2	3
18 –20	0	0	1	1
20 –22	2	0	0	3
22 –24	0	1	2	0
24 –26	0	0	1	1
26 –28	1	0	0	1
28 –30	0	0	0	3
30 –32	0	0	1	0
32 –34	2	0	0	0
34 –36	0	0	1	2
36 –38	0	0	1	1
38 –40	0	0	1	0
40 –42	0	0	1	0
42 –44	0	0	0	0
44 –46	0	0	0	1
46 –48	0	0	1	1
48 –50	0	0	1	1

unproved clusters. Fig. 2 gives the frequency when the results are treated irrespective of the sign of β, and shows more clearly the apparent relation of open and globular clusters. A few globular systems in high galactic latitude are not represented in the diagrams, and for $\beta \geqq 10°$ the numbers of Table I for both globular and open clusters have been combined into small groups in drawing the curves.

[1] A few of the latitudes of Table V (*op. cit.*) have been slightly revised, as noted in the third section of the present contribution.

If for β, the angular distance from the plane, we were able to substitute the linear distance, $R \sin \beta$, the mid-galactic maximum for the open clusters would be closely restricted around the vertical axis; and the two maxima of the dotted curve would be relatively much steeper on the side nearer the vertical axis, showing that the galactic zone is entirely clear of globular clusters.[1]

Clusters of Melotte's Class II are more compact and populous than those of Class III, but the distribution in galactic latitude is

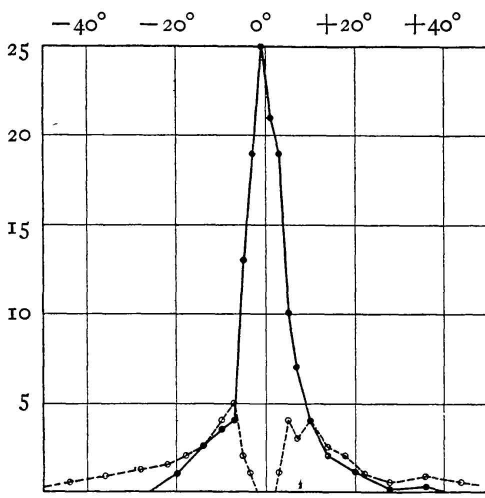

FIG. 1.—Frequency in galactic latitude of open clusters (full line) and globular clusters (broken line). Ordinates are numbers of clusters; abscissae are angular distances from the galactic plane.

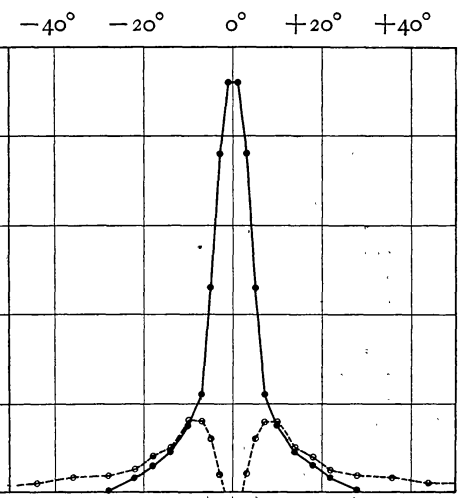

FIG. 2.—Reflected frequency-curve of galactic latitudes for open clusters (full line) and globular clusters (broken line).

essentially the same for both types. Choosing from all the data the twenty richest and most regular open clusters, we find the following distribution in galactic latitude:

β	$<-4°$	$-4°,-3°$	$-2°,-1°$	$-0°,+0°$	$+1°,+2°$	$+3°,+4°$	$>+4°$
Number of Clusters	2	4	4	3	5	2	0

This certainly does not show a concentration to the medial plane; but perhaps it does not indicate as marked an avoidance of that plane as might be expected if we assume that globular systems are more closely allied to rich clusters than to the average open group.

[1] Cf. Fig. 6 of the seventh paper of this series.

II. THE DISTANCES OF 17 ADDITIONAL GLOBULAR CLUSTERS

A year ago 69 clusters were accepted as definitely globular.[1] Since that time special efforts have been made to examine with the 60-inch reflector the suspected and doubtful cases north of declination $-30°$ that had not been admitted to the earlier lists. The experience gained as a consequence of photographing faint and abnormal systems has also afforded a basis for better judgment in accepting or rejecting the clusters too far south for observation at Mount Wilson. Some unpublished observations of clusters with the Crossley reflector at the Lick Observatory were generously placed at our disposal by Professor Curtis. While at Mount Wilson during the past summer Professor Duncan, of Wellesley College, kindly made some long exposures on clusters with the 60-inch reflector.

Results of the survey of doubtful cases are summarized in Table II. In addition a number of clusters concerning which some doubt existed,[2] such as N.G.C. 4147, 6144, 6656, 6712, and 7006, have been proved during the year to be entitled to places in the lists; none of the 69 original clusters should be withdrawn, as far as the present observations go.

As in *Mount Wilson Contributions*, No. 152, the treatment of individual cases must be omitted. The distances, which in general cannot claim as high accuracy as those previously studied, depend for the most part upon diameters, since the objects in many cases are so faint that accurate analysis of the magnitudes would have been too laborious. Exposures of several hours were occasionally necessary to test for globularity. Frequently systems that shorter exposures had shown with some definiteness to be open[3] proved upon more persistent observation to be globular. At present there is hardly another object, north of $-30°$ at least, that is suspected with good reason of being a globular cluster.

Three points relative to the large distances are worthy of comment. (1) Practically all of these additional systems are more distant than 30,000 parsecs (100,000 light-years), thereby confirming an

[1] Tables V and VIII of *Mt. Wilson Contr.* No. 152, 1917.

[2] *Op cit.*, p. 9, n. 2.

[3] *Op. cit.*, p. 14, n. 2.

earlier surmise as to the completeness of the survey of globular clusters within that distance of the sun. (2) Every recognized globular cluster except one bears a number from the *New General Catalogue*, thus testifying that, in spite of distance and faintness, all of these remote objects were known prior to 1888. In fact, all but this one exception were known before 1864, the date of the *General Catalogue*, and all but three or four had already been catalogued by the

TABLE II

PARALLAXES OF 17 CLUSTERS

N.G.C.	R. A. 1900	Decl. 1900	Galactic Long.	Galactic Lat.	Distance (Unit is 100 Parsecs) Radial	Projected on Galactic Plane	From Galactic Plane
*5466	14^h $1^m.0$	+29° 0′	10°	+72°	195:	60	+180
†I.C. 4499	14 45.0	−81 49	274	−20	250	235	− 85
*5927	15 20.8	−50 19	294	+ 5	185	185	+ 16
‡5946	15 28.2	−50 19	295	+ 4.0	415	415	+ 29
‡6355	17 17.8	−26 15	327	+ 4.4	500	500	+ 38
*6366	17 22.4	− 4 59	346	+16	320	310	+ 89
*6426	17 39.9	+ 3 13	356	+15	570	550	+150
*6440	17 42.9	−20 19	336	+ 2.5	525	525	+ 23
‡6496	17 51.8	−44 14	315	+11	305:	300	+ 58
*6517	17 56.4	− 8 57	347	+ 5	625	625	+ 55
‡6535	17 58.7	− 0 18	354	+10	370:	365	+ 64
†6539	17 59.4	− 7 35	348	+ 6	400	400	+ 42
†6553	18 3.2	−25 56	332	− 3.4	320	320	− 19
‡6558	18 3.8	−31 47	327	− 6	455	450	− 48
*6569	18 7.2	−31 51	328	− 7	400	395	− 49
†6760	19 6.1	+ 0 52	3	− 4.6	525	525	− 42
*7492	23 3.1	−16 10	21	−64	285	125	−255

* Certainly a globular cluster.
† Almost certainly a globular cluster.
‡ Probably a globular cluster but as yet not proved.

Herschels or earlier observers more than eighty years ago. This is further evidence of the completeness of our lists of globular clusters. (3) N.G.C. 7006, with adopted distance of 67,000 parsecs, still holds its place as the most remote sidereal object of definitely estimated distance.

Further observations are likely to prove that N.G.C. 6355 and 6535 are globular, but present photographs of them are hardly conclusive. The other three unproved systems are too far south for the 60-inch reflector.

Perhaps the most striking result of this special survey is the evidence that every faint, little-condensed cluster in galactic latitude higher than 15° or 20° is really globular, although short exposures and visual observations had in several cases heretofore recorded few stars. On the other hand, the similar faint clusters along the galactic equator, without exception, are open groups with no condensed background of faint stars appearing on long exposures. N.G.C. 7492, for instance, was formerly considered an exception[1]—an open cluster outside the galactic segment—but it is actually globular, containing thousands of stars. The evidence grows continually stronger that open and globular clusters occupy regions of space that are mutually exclusive.

There is also some evidence that an abnormal type of globular cluster exists, one in which the brighter stars are fainter and more scattered than is usually the case. In their luminosity-curves a distinct break appears to occur between the brighter and fainter stars, and for such systems the parallax-diameter relation may not be strictly applicable. The known examples of this type are N.G.C. 5466, 6366, and 7492; it might be well also to place N.G.C. 4372, 5897, and 6144 in this group, although for two of them an alternative interpretation of the apparent discrepancy between diameter and magnitude may be available.[2] The abnormal form possibly represents an early or late stage, or a disturbed condition of a typical globular cluster. In N.G.C. 7492, for which some preliminary colors are available, the brightest stars are yellow.

III. ON THE DISTRIBUTION IN SPACE OF 86 GLOBULAR CLUSTERS

For the reasons apparent from the following remarks it seems worth while to revise the plots and extend the discussion of the distribution in space of globular clusters. Fig. 3 shows the projection on a plane perpendicular to the Galaxy and oriented to include galactic longitude 325°. It gives the appearance of the system of clusters as seen from longitude 235° and is thus merely a revision

[1] *Publications of the Astronomical Society of the Pacific*, **30**, 50, 1918.

[2] *Mt. Wilson Contr.* No. 152, p. 14, n. 2, 1917.

of Fig. 4 of the seventh paper of this series.[1] The values of the abscissae, $R \cos\beta \cos(\lambda-325^\circ)$, were determined graphically for

TABLE III

SPACE CO-ORDINATES OF GLOBULAR CLUSTERS

N.G.C.	$R \sin\beta$	$R \cos\beta$-$\cos(\lambda-325^\circ)$	$R \cos\beta$-$\sin(\lambda-325^\circ)$	N.G.C.	$R \sin\beta$	$R \cos\beta$-$\cos(\lambda-325^\circ)$	$R \cos\beta$-$\sin(\lambda-325^\circ)$
104....	−47	+29	−39	6341....	+69	+33	+96
288....	−189	−3	−7	6352....	−28	+216	−66
362....	−109	+58	−89	6355*...	+38	+500	+18
1261....	−199	+8	−161	6356....	+67	+375	+59
1851....	−96	−58	−131	6362....	−38	+105	−66
1904....	−120	−145	−173	6366....	+89	+290	+111
2298....	−63	−88	−219	6388....	−34	+269	−62
2808....	−32	+40	−162	6397....	−17	+76	−29
3201....	+26	+23	−143	6402....	+56	+207	+92
4147....	+514	−23	−107	6426....	+150	+471	+283
4372....	−18	+63	−94	6440....	+23	+516	+100
4590....	+97	+70	−108	6441....	−40	+452	−32
4833....	−23	+96	−132	6496*...	+58	+296	−52
5024....	+186	+34	−11	6517....	+55	+579	+234
5139....	+18	+41	−46	6535*...	+64	+319	+177
5272....	+136	+20	+21	6539....	+42	+368	+156
5286....	+37	+134	−139	6541....	−28	+142	−22
5466....	+180	+42	+42	6553....	−19	+318	+39
5634....	+229	+191	−55	6558*...	−48	+450	+16
I.C. 4499	−85	+148	−183	6569....	−49	+395	+21
5897....	+75	+125	−31	6584....	−73	+243	−70
5904....	+90	+86	+11	6624....	−40	+282	+25
5927....	+16	+159	−95	6626....	−19	+181	+32
5946*...	+29	+359	−208	6637....	−41	+209	+15
5986....	+47	+191	−69	6638....	−48	+337	+60
6093....	+65	+188	−16	6652....	−65	+305	+16
6101....	−55	+156	−135	6656....	−12	+80	+18
6121....	+31	+109	−13	6681....	−41	+177	+12
6144....	+63	+235	−25	6712....	−32	+274	+145
6171....	+60	+148	+16	6715....	−44	+153	+22
6205....	+71	+40	+75	6723....	−39	+121	+4
6218....	+52	+106	+34	6752....	−39	+73	−30
6229....	+274	+82	+328	6760....	−42	+414	+323
6235....	+112	+487	+8	6779....	+30	+105	+225
6254....	+45	+106	+32	6809....	−41	+90	+16
6266....	+19	+150	−13	6864....	−206	+376	+152
6273....	+25	+157	−3	6934....	−114	+180	+256
6284....	+64	+364	0	6981....	−164	+192	+150
6287....	+83	+428	+15	7006....	−228	+245	+577
6293....	+37	+261	0	7078....	−69	+49	+121
6304....	+28	+320	−11	7089....	−94	+70	+104
6316....	+46	+524	0	7099....	−128	+101	+56
6333....	+43	+244	+34	7492....	−255	+70	+104

* Probably a globular cluster but not definitely proved.

[1] *Mt. Wilson Contr.* No. 152, 1917. The point for M 75 (N.G.C. 6864) is erroneously plotted in the earlier figure.

the earlier plot; they are now computed and entered in the third column of Table III. All globular clusters are represented in the new diagram, including the five unproved objects marked with the double dagger in Table II. The open circles designate clusters for which the provisional distances are marked in Table II by a colon.

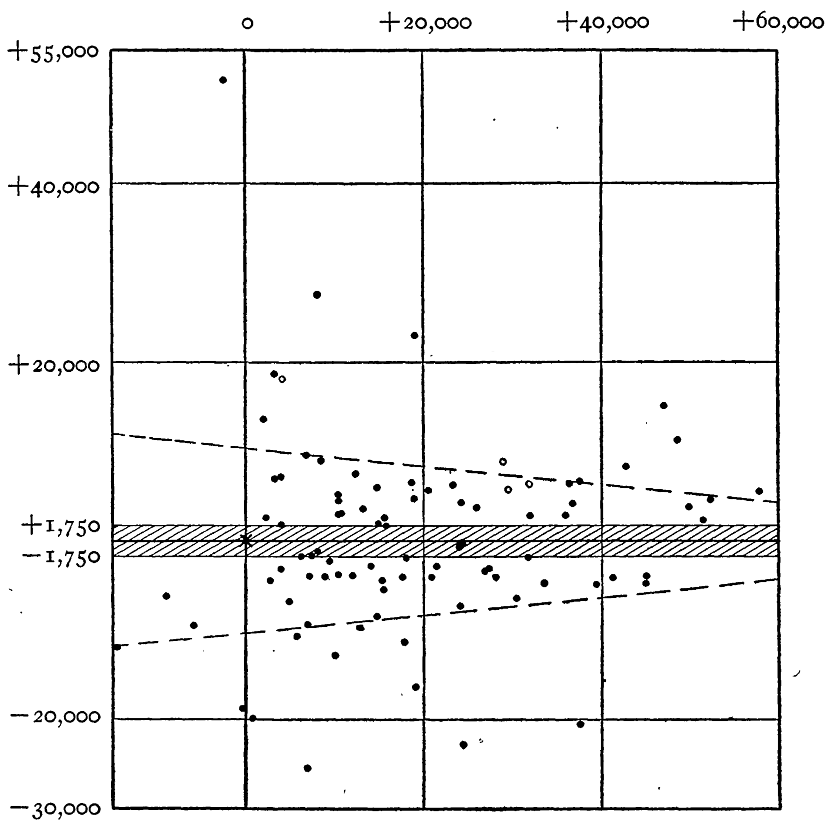

FIG. 3.—Projection of the complete system of globular clusters on a plane perpendicular to the Galaxy and oriented to include the line from the sun to the center of the system. Ordinates are $R \sin \beta$; abscissae are $R \cos \beta \cos (\lambda - 325°)$; unit of distance is one parsec. The sun at the origin of co-ordinates is marked by a cross. See Fig. 4 of *Mt. Wilson Contr.* No. 152.

The parallax of Messier 22 (N.G.C. 6656) has been increased slightly over the value previously adopted. The cluster is fairly open and in a rich field, and it is now found that the stars selected for the study of magnitudes were so near the center that an error of 0.15 mag., due to the Eberhard effect, crept into the earlier results. The values of the galactic co-ordinates for some of the

clusters in Table V of the seventh paper were taken from the catalogues of Bailey, who used a position of the North Galactic Pole slightly different from that adopted for this work. The computations in Table III are all based on the co-ordinates in Melotte's catalogue, with the result that the new values of $R \sin \beta$ differ in a few cases from those previously computed. The revised galactic positions, however, never differ by more than a degree in either co-ordinate, except for the longitudes in high galactic latitude.

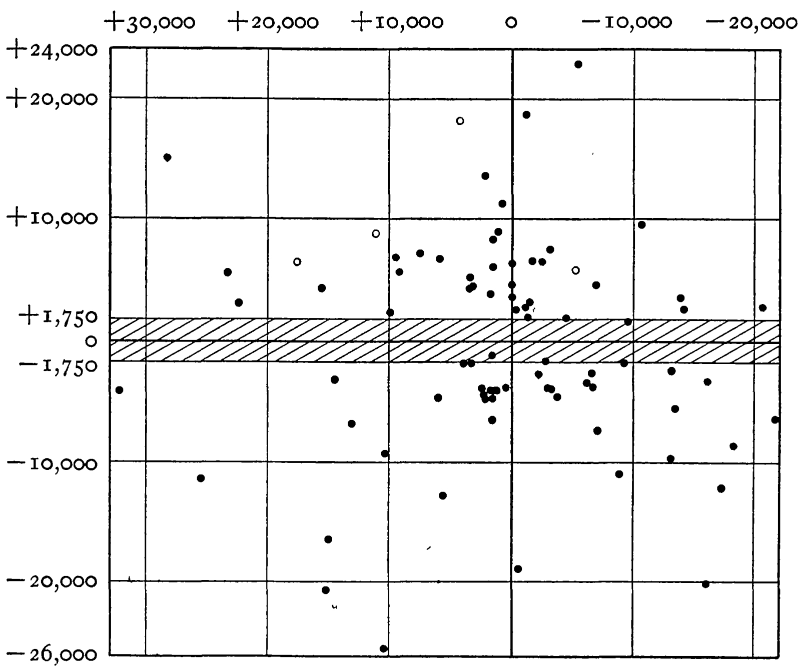

FIG. 4.—Projection of the system of globular clusters on a plane perpendicular to the Galaxy and to the plane of the preceding diagram. Ordinates are $R \sin \beta$; abscissae are $R \cos \beta \sin (\lambda - 325°)$.

Three points formerly not definite are now emphasized by Fig. 3: (1) There is no sensible increase in the minimum distance from the galactic plane with increasing distance from the sun. (2) The additional results have filled in the gaps of the earlier work and show that the provisional estimate of a distance of 20,000 parsecs to the center of the system is not too great. (3) There is evidence that the globular clusters occupy a space shaped somewhat like a split wedge, the base of which passes nearly through the

sun and contains the great circle defined by galactic longitudes 55° and 235°. Only a part of the tapering of the wedge beyond the center of the system is to be attributed to a lack of observations. The inclined broken lines in Fig. 3 suggest the degree of tapering away from the extremely broad and sharply defined base.

Fig. 4 shows the projection of globular clusters on a plane perpendicular to the Galaxy and to the plane of Fig. 3. It represents the appearance of the system of clusters as seen from a great distance in longitude 145°, indicating approximately the apparent distribution as seen from the earth. The co-ordinates for this plot are in the second and fourth columns of Table III. The close approach to symmetry when viewed from this angle is interesting; the numbers of clusters in the four quadrants are 20, 23, 23, and 20. N.G.C. 4147, 6229, and 7006 are outside the limits of the figure.

It is a striking fact that the system of 86 globular clusters listed in Table III is divided into exactly equal numbers by the plane of the Milky Way.

IV. NOTE ON THE ABSENCE OF GLOBULAR CLUSTERS FROM MID-GALACTIC REGIONS

In the seventh and twelfth papers of this series[1] comments have been made upon the absence of globular clusters from the equatorial region of the galactic system. The importance of the phenomenon necessitates a full consideration of its reality and meaning. That the condition is real is attested by such evidence as: (1) the consistent agreement of the results for clusters at various intervals of distance along the galactic plane; (2) the presence of blue stars and open clusters on the galactic equator at distances equal to those of the nearer globular clusters; (3) the absence of appreciable light-scattering in space; and, finally, (4) the apparent dynamical relation of globular to open clusters and their complementary distribution.

Probably the best evidence that dark nebulosity does not obscure globular clusters in the equatorial segment (the nebulous clouds assumed, for instance, to be analogous to the peripheral

[1] *Mt. Wilson Contr.* No. 152, p. 22, 1917; No. 157, pp. 6, 10, 1918.

ring of absorbing matter observed in some spiral nebulae) is afforded by the diagram of Fig. 5. Let us consider first the 31 globular clusters for which the distance projected on the plane of the Milky Way, $R \cos \beta$, does not exceed 15,000 parsecs. Fifteen are north of the galactic plane and sixteen are

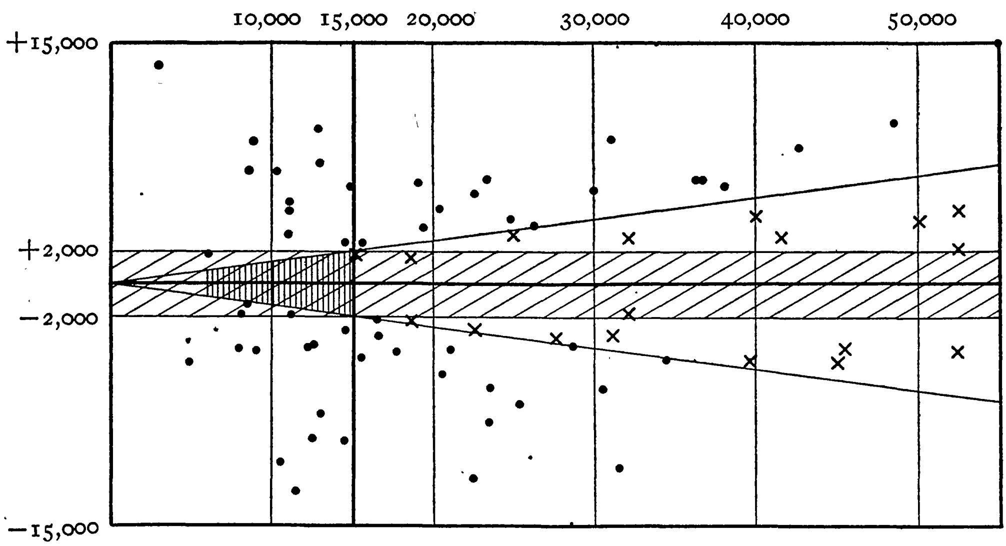

FIG. 5.—Diagram to illustrate that the equatorial segment may not be devoid of globular clusters because of clouds of obstructing matter in the Milky Way. Ordinates are $R \sin \beta$; abscissae are $R \cos \beta$; the unit of distance is one parsec. Twelve clusters fall outside the limits of this diagram.

south. Their frequency in distance from the plane, $R \sin \beta$, is as follows, the unit of distance being 100 parsecs:

$R \sin \beta$	$> \pm 200$	± 200 to ± 150	± 150 to ± 100	± 100 to ± 75	± 75 to ± 50	± 50 to ± 25	$< \pm 25$	-12 to $+18$
Number	3	2	3	5	5	9	4	0

This tabulation, as well as the part of the diagram to the left of the heavy vertical line, shows definitely the absence from the Milky Way of the nearer clusters.

If we attribute the absence of globular clusters to the obscuration by dark matter in low latitudes, we may indicate this hypothetical obscuring material by the vertical shading across the equatorial segment. If the nearby clusters are missing because of these clouds of obstructing matter, then certainly the faint and more distant clusters behind the clouds should be wanting. That

is, the light from every visible cluster with galactic latitude less than $\pm 8^\circ$ would pass through this region, which, by supposition, is capable of concealing twenty or thirty systems that are relatively near. To maintain the assumption, no clusters should be found within the diverging lines. Observation shows nearly a score. The supposition, therefore, that the mid-galactic regions are not transparent appears untenable.

During the six months that have elapsed since the preceding paragraphs were written some doubt has been thrown on the foregoing conclusion, notwithstanding the amount and character of the evidence in its favor. A discussion of the new arguments and the observational data will be given elsewhere in connection with a treatment of the parallaxes of open clusters. For the present the reality of the avoidance of the galaxy by globular clusters must be considered an open question.

We cannot suppose that the 19 clusters[1] within the diverging lines have been estimated too distant because of partial obstruction of their light, and that they are actually the clusters missing from the nearer equatorial segment. The distances of these clusters are based upon angular diameters, some upon magnitudes as well, and we have found that the parallax-diameter relation holds whether the clusters are near or far from the galactic plane.[2]

V. ON THE PARALLAX-DIAMETER RELATION FOR GLOBULAR CLUSTERS

The relation between the distances, as determined both from variable stars and from mean magnitudes, and the apparent diameters, as measured on the Franklin-Adams charts, is unexpectedly definite, if we consider the various constitutional differences among globular clusters.[3] The relatively small deviations from the parallax-diameter curve[4] appear to mean that abnormal clusters are rare. That the correlation of distance and apparent diameter is

[1] One cluster with $R \sin \beta = +5500$ parsecs falls outside the diagram to the right.

[2] In the sixth section of this paper the additional parallax-diameter curves are definite, notwithstanding the large differences in exposure-time and in the brightness of the stars appearing in the photographs.

[3] For instance, the occasional contrast in concentration of the brighter stars, noted in the second section of this paper.

[4] Fig. 1 of *Mt. Wilson Contr.* No. 152.

actually fundamental, however, and is therefore reliably applicable to the estimation of parallaxes not otherwise obtainable, is further attested by the supplementary data represented in the curves of Fig. 6, which we shall presently describe.

The significance of these fairly uniform results must be that, for the large majority of globular clusters, the linear dispersion of the central nucleus[1] is nearly constant, although we cannot as yet decide definitely whether that condition connotes approximately simultaneous origin of all known extra-galactic cluster systems, or rather an essentially permanent dynamical condition in spheroidal stellar groups. The second alternative is supported by the evidence of numerous open galactic clusters. Such groups appear to maintain dimensions of the same order as those of globular systems, but they show, in the scarcity of their red giants and the preponderance of highly luminous blue stars, indications either of much greater age or of more expeditious development.

Without doubt the most homogeneous photographic survey now available for the whole sky is that initiated by Mr. Franklin-Adams;[2] the uniform length of exposure, the quality of stellar images, and the scale of the photographic charts are all particularly suitable for the study of the composite images of clusters, reported in *Mount Wilson Contributions*, No. 152.

We have a second comprehensive photographic survey in the Harvard Map of the Sky, but the copies (positive prints on glass) of the originals show considerable lack of homogeneity in quality and limiting magnitude;[3] in particular, the scale of the plates is so small (aperture 1 inch, focal length 13 inches, exposures 39 to 75 minutes) that high accuracy cannot be expected in determining the apparent diameters of the nearly starlike images of globular clusters.[4] Notwithstanding the difficulties due to faintness, small

[1] The estimates of diameter on the Franklin-Adams charts "refer actually to what appears to be a central core of each system. The scale of the photographs does not permit close differentiation of the outlying members of a cluster from the stars of its surrounding field," p. 25, n. 1, *Mt. Wilson Contr.* No. 152.

[2] *Memoirs of the Royal Astronomical Society*, 60, Part 3, 1915.

[3] Cf. Nort, *Recherches Astronomiques de l'Observatoire d'Utrecht*, VII, 1917.

[4] The Harvard Map is described in *Harvard Circular*, No. 71, 1903.

size, and the resulting confusion with the surrounding fields, the mean results show, in the upper curve of Fig. 6, a definite progression of apparent diameter with adopted parallax. Each point represents the mean of five values. Many of the most distant clusters could not be certainly identified on this scale; and ω Centauri, with diameter 22′.6, parallax 0″.00015, is also not plotted. The deviations for the individual clusters average nearly 25 per cent of

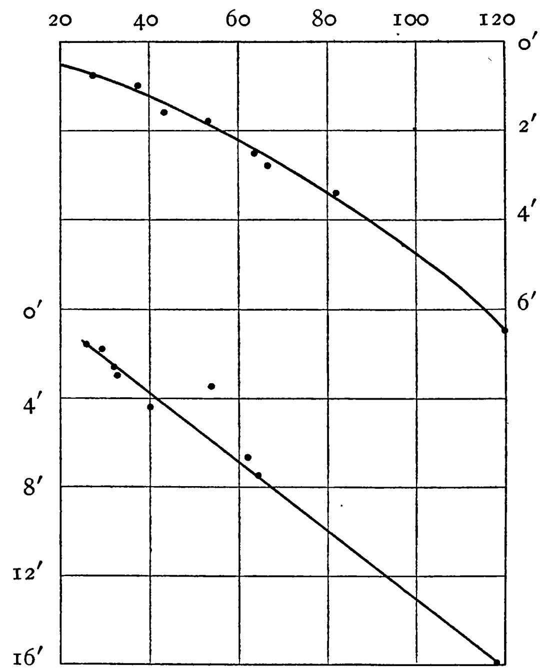

FIG. 6.—Parallax-diameter curves for globular clusters. Above: diameters from plates of Harvard Map of the Sky; below: diameters from Palisa-Wolf charts; ordinates are diameters; abscissae are parallaxes in units of 0″.000001.

the adopted parallaxes, a decidedly lower accuracy than shown by results from the Franklin-Adams charts[1] but still of considerable value as a further justification of the method and as a check of the separate values.

The photographs of the Milky Way by Bailey[2] are also serviceable for this work, since many of the globular clusters lie within 10° of the galactic circle. The scale of his photographs is about the

[1] Cf. Table VII of *Mt. Wilson Contr.* No. 152.

[2] *Harvard Annals*, **72**, No. 3, 1913; **84**, No. 4, 1916.

same as for the Harvard Map, and a casual examination gives comparable results.

The scale of the photographic charts published by Palisa and Wolf is more than double that of the Franklin-Adams charts, but the series is incomplete and the exposure times for the few plates that contain clusters vary from 1^h40^m to 3^h30^m. The results for the nine clusters available are in the lower part of Fig. 6; they suggest the high value of a complete series of long exposures on the larger scale, and they again emphasize the validity of this manner of estimating distance. The discordant point refers to N.G.C. 6626, a compact cluster in declination $-25°$.

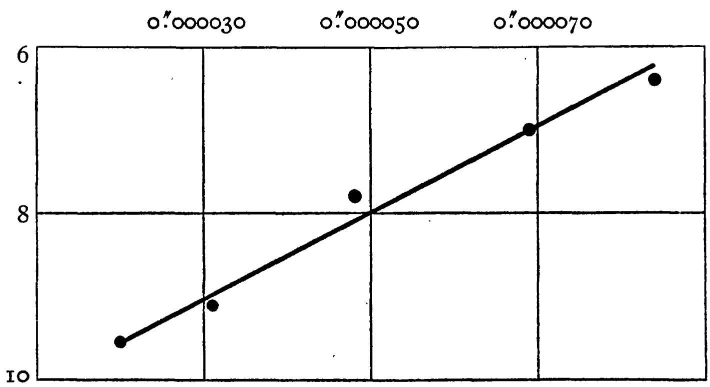

FIG. 7.—Parallax and integrated visual magnitude. Ordinates are Holetschek's magnitudes; abscissae are adopted parallaxes.

Nearly all of the values of diameter used in this section are based upon two independent series of measures by Miss Davis.

VI. TOTAL LIGHT AS A MEASURE OF THE DISTANCES OF CLUSTERS

The mean apparent magnitude of the 25 brightest stars in a globular cluster has been used with satisfactory results as a criterion of distance.[1] The integrated apparent brightness of the same stars, or even of the hundred or so brightest stars in each system, would probably be an equally good measure of the distance. The integrated light of all the thousands of stars in a globular cluster, however, does not greatly exceed that due to its brightest stars alone;

[1] See the fifth section of the sixth paper of this series, *Mt. Wilson Contr.* No. 151, 1917.

and if it were possible, after overcoming some of the obvious minor difficulties, to measure accurately the total apparent brightness of such systems, possibly a valuable method would result for deriving the relative parallaxes of all typical globular groups.

A study has been made by Holetschek[1] of the integrated visual magnitudes of the brighter clusters and nebulae visible at Vienna. His adopted magnitudes for globular clusters, given in Table IV, are of very unequal merit owing to disparity of observation, varying diffuseness of images, and availability of comparison stars. Magnitudes of the comparison stars were taken in general from the B.D.

TABLE IV

HOLETSCHEK'S INTEGRATED MAGNITUDES OF GLOBULAR CLUSTERS

N.G.C.	Mag.	Parallax	N.G.C.	Mag.	Parallax	N.G.C.	Mag.	Parallax
1904......	8.0	39	6229....	8.6	23	6637....	9.0	47
4147......	9.4	19	6235....	9.7	20	6656....	6.2	118
4590......	8.2	62	6254....	6.9	83	6681....	9.5	55
5024......	7.8	53	6266....	7.0	66	6712....	8.9	32
5272......	6.6	72	6273....	6.8	63	6760....	10.5	19
5466......	8.5	51	6284....	9.5	27	6779....	8.3	40
5634......	9.7	33	6287....	9.2	23	6864....	8.0	22
5897......	10.2	67	6293....	8.5	38	6934....	9.0	30
5904......	6.7	80	6333....	7.3	40	6981....	9.5	34
6093......	7.8	50	6341....	6.2	81	7006....	9.7	15
6121......	6.8	88	6356....	8.5	26	7078....	6.2	68
6171......	9.0	62	6402....	7.8	43	7089....	6.7	64
6205......	5.8	90	6626....	7.9	54	7099....	8.5	58
6218......	6.8	81						

catalogues, and high accuracy is not claimed for the results. The parallaxes in Table IV are the adopted values from *Mount Wilson Contributions*, No. 152; the unit is 0.″000001.

Omitting the magnitudes for clusters south of declination $-20°$ because of uncertainties connected with low altitude and short observing season, we have combined the remaining twenty-three values into normal groups in order of parallax. The plot of the normal points in Fig. 7 shows the expected uniform decrease of brightness with increasing distance. Obviously a systematic comparison with recognized magnitude standards, using a telescope of

[1] *Annalen der k.k. Universitäts-Sternwarte in Wien*, **20**, 114, 1907.

extremely short focus, or a method that is independent of the angular diameters of the images compared, would contribute important material to the problem of the relative parallaxes of star clusters.

VII. THE CONTRASTED MOTIONS AND DISTRIBUTION OF GLOBULAR CLUSTERS AND SPIRAL NEBULAE

The known radial velocities of globular clusters are predominantly negative.[1] These enormous stellar systems, moving under gravitational attraction with an average speed of more than 100 km/sec., are apparently as a class approaching the sun; and, remembering their extra-galactic positions, we also infer that they are approaching and falling into the dense stellar strata of the general galactic system. To be sure, the spectroscopic study of clusters has not gone far as yet, but the foregoing inference does not rest upon observed velocities alone. The composition of the galactic system and the distribution of clusters in space, especially the relation of globular systems to the open groups of mid-galactic regions,[2] yield more important evidence than is afforded by radial velocities that the galactic system absorbs globular clusters.

On the other hand, the brighter spiral nebulae as a class, apparently regardless of the gravitational attraction of the galactic system, are receding from the sun and from the galactic plane—a remarkable condition that has been little emphasized heretofore. From the published spectroscopic work of Adams, Campbell, Moore, Paddock, Pease, Sanford, Wolf, Wright, and particularly of V. M. Slipher at Flagstaff, we obtain the radial velocities in the fifth column of Table V. The Andromeda nebula (N.G.C. 224) and its companion are treated as a single object. The radial velocity of the nucleus of Messier 33, as determined by Pease from absorption lines, is given in preference to the earlier values derived by Pease and Slipher from bright lines.[3]

Limited as this material is, it yields some important results, which emphasize the contrast between clusters and spiral nebulae

[1] See *Mt. Wilson Contr.* No. 157, 1918, Table I and Section 6.

[2] Sections I and III of this paper.

[3] *Publications of the Astronomical Society of the Pacific*, **28**, 33, 1916.

and bear directly upon the structure and present status of the galactic system. These preliminary results, appearing in the seven numbered divisions below, are the more worthy of mention at the present time because the increase of observational data for spirals will necessarily be slow from now on, due to the extreme faintness of the nebulae not already observed for radial velocity.

TABLE V

POSITIONS AND RADIAL VELOCITIES OF 25 SPIRAL NEBULAE

N.G.C.	Messier	Galactic Long.	Galactic Lat.	Radial Velocity	Apical Distances, θ $\omega=90°$	$\omega=105°$	$\omega=120°$	$\omega=150°$	Vis. Mag. (Holetschek)
				km					
224......	31	89°	−20°	− 316	20°	25°	36°	63°	5.0
598......	33	102	−30	− 70	32	30	35	55	7?
1023......	....	112	−19	+ 300	29	20	21	42	9.7
1068......	77	141	−52	+1120	67	60	55	52	8.7
2683......	....	158	+40	+ 400	73	63	53	41	9.2
3031......	81	109	+42	− 30	45	42	43	56	8.0
3115......	....	216	+38	+ 600	118	106	95	71	9.0
3379......	....	218	+59	+ 810	108	102	94	79	9.1
3521......	....	225	+54	+ 730	115	107	99	81	9.3
3623......	65	209	+64	+ 800	102	96	90	77	8.9
3627......	66	211	+64	+ 650	103	97	90	78	8.6
4151......	....	118	+76	+ 940	78	76	76	78	10.7
4258......	....	103	+68	+ 500	69	68	69	75	8.7
4526......	....	262	+71	+ 580	109	107	105	97	10.0
4565......	....	215	+88	+1100	91	91	90	89	9.4
4594......	....	267	+52	+1180	128	126	121	106	8.7
4649......	60	265	+75	+1090	105	104	102	96	8.6
4736......	94	76	+86	+ 290	86	86	87	89	7.7
4826......	64	295	+84	+ 150	95	96	96	95	8.6
5005......	....	64	+78	+ 900	79	81	83	89	9.1
5055......	63	69	+74	+ 450	75	77	80	88	9.2
5194......	51	68	+71	+ 270	72	75	78	87	8.4
5236......	83	283	+31	+ 500	147	148	145	126	9.5
5866......	....	59	+52	+ 650	58	65	73	91	10.3
7331......	....	62	−22	+ 500	35	47	61	88	9.3

1. Since the greater number of bright spirals are north of the galactic plane and their positions are more favorable for northern observers, only five negative galactic latitudes appear in Table V. To these should be added that of N.G.C. 1700, for which Sanford estimates a large positive velocity, though, in the absence of a definite numerical value, it is not included in the table. Only one of the twenty velocities for spirals north of the plane is negative,

while two of the spirals on the south side are approaching. But the three negative values depend, as we shall see, on low galactic latitude and high apparent brightness rather than on the sign of the latitude, and hence we conclude that essentially without exception, on both sides of the Galaxy, spiral nebulae recede.

2. The speed of spiral nebulae is dependent to some extent upon apparent brightness, indicating a relation of speed to distance or, possibly, to mass. The six spirals with smallest radial velocity, including all of those with negative values, are not exceeded in brightness by any spirals in Holetschek's list of visual magnitudes:[1]

N.G.C.	224	598	4736	3031	5194	4826
Integrated magnitude	5.0	7?	7.7	8.0	8.4	8.6
Radial velocity	−316	−70	+290	−30	+270	+150 km

The arithmetical mean of these six velocities is ±188 km/sec.; their algebraic mean is +49 km/sec., while for the other 19 spirals of Table V it is fifteen times as large—that is, +726 km/sec. Only three spirals besides these six bright ones are now known to have radial velocities of less than +500 km/sec.

3. Forming means of five in order of galactic latitude, we derive from Table V the first two lines of the following tabulation, which indicate that speed may be related to angular distance from the galactic equator:

Mean galactic latitude, β	24°	45°	59°	72°	82°
Mean radial velocity, V_r	+183	+548	+834	+578	+676 km
$V_p = V_r$ cosec β	+450	+775	+975	+610	+680 km

If we should assume that the motion is wholly perpendicular to the galactic plane, the mean velocities would be as given in the last tabulated line above.

4. The correlation of velocity and the latitude co-ordinate, although not very definite, may be of some significance for theories of the spiral nebulae; but, guided by the provisional hypothesis described in Section VIII of this paper, we find some evidence of a more striking relation between the velocities of spirals and a new position co-ordinate. Let λ and β denote the galactic

[1] *Annalen der k.k. Universitäts-Sternwarte in Wien*, **20**, 114, 1917. N.G.C. 4826 is equaled in brightness by two other spirals, according to Holetschek's estimates.

co-ordinates of any spiral, and ω the longitude of an origin on the galactic circle. Then the angular distance, θ, of the spiral from this origin is given by

$$\cos\theta = \cos\beta \cos(\lambda - \omega) \tag{1}$$

In the last four columns of Table V we give for each spiral the values of θ for $\omega = 90°$, $105°$, $120°$, $150°$. The angle θ may lie between 0° and 180°, and at the galactic poles is 90°; in the table, however, no value of θ is less than 20° because of the avoidance of the Milky Way by spiral nebulae, and few values exceed 120° because the most southern nebulae have not been observed for velocity.

TABLE VI

THE PROGRESSION OF THE MEAN VELOCITY OF SPIRAL NEBULAE WITH DISTANCE FROM THE GALACTIC APEX

Interval of θ	$\omega = 90°$			$\omega = 105°$			$\omega = 120°$		
	Mean θ	Mean V_r	Number	Mean θ	Mean V_r	Number	Mean θ	Mean V_r	Number
$\leqq 50°$..	32°	+ 77	5	33°	+ 77	5	34°	− 29	4
51°– 75 ..	69	+565	6	66	+588	5	62	+634	5
76 –100 ..	86	+676	5	88	+660	8	88	+641	12
101 –125 ..	109	+751	7	105	+762	5	109	+950	3
> 125 ..	138	+840	2	137	+840	2	145	+500	1

For the first three values of ω the progression of the observed radial velocity of spirals, V_r, with increasing θ is shown in Table VI for equal intervals of θ. The interval for θ less than 50° contains in all cases the three bright nebulae with negative radial velocities, and the mean V_r is correspondingly affected. The correlation, if real, is about equally definite for $\omega = 90°$ and $\omega = 105°$. Its meaning would be that, regardless of galactic latitude, the average radial velocity of spiral nebulae increases with the angular distance from a point in the northern Milky Way—a point which, in anticipation of an explanation proposed in Section VIII, we may call the galactic apex.

In these progressions we have a suggestion that average radial velocity may be roughly predicted from position; but before this relation can be definitely established from spectroscopic results alone, we must have more data, for the wide range of peculiar

velocity in Table V is inadequately reflected by the means of Table VI. Other groupings could alter or even conceal the uniform progression of mean velocities.

If we omit the two brightest nebulae for the sake of greater homogeneity (see p. 126) and combine the others into four groups in order of increasing θ, we obtain for $\omega=105°$:

Mean θ	46°	74°	95°	116°	(2)
Mean V_r	+458	+618	+633	+780 km	
Number of spirals	5	6	6	6	

5. On the basis of this more homogeneous material we may make the following computation, which is perhaps to be considered more as an interesting illustration than as an approach to definite cosmic fact. Let V_s be the average systematic recessional velocity of spiral nebulae in the line of sight, and let V_g be a quantity which we may call the velocity of the galactic system toward $\lambda=105°$, $\beta=0°$. Then

$$V_s - V_g \cos\theta = V_r \tag{3}$$

and from the values of θ and V_r in (2) we obtain, provisionally,

$$\begin{aligned} V_s &= +650 \text{ km/sec.} \\ V_g &= +300 \text{ km/sec.}^{1} \end{aligned} \tag{4}$$

Employing these provisional values of V_s and V_g, and setting up conditional equations of the form (3) for each of the 23 spirals in the tabulation (2), we derive the following normal equations:

$$\begin{aligned} 23\Delta V_s - 1.96\Delta V_g - 120 &= 0 \\ -1.96\Delta V_s + 4.34\Delta V_g + 80 &= 0 \end{aligned}$$

The solution gives for corrections to (4), $\Delta V_s = +8$ km/sec., $\Delta V_g = +17$ km/sec. The adopted values with their probable errors are

$$\begin{aligned} V_s &= +660 \pm 45 \text{ km/sec.} \\ V_g &= +320 \pm 100 \text{ km/sec.} \end{aligned}$$

The average difference between an observed velocity and that computed by putting the foregoing values in formula (3) is ± 240

[1] By assuming $V_g = +300$ km/sec., the mean value of V_s derived from *all* the material of Table VI is +635 km/sec. for $\omega=105°$, in close agreement with the result above.

km/sec., a quantity that is to be taken as representing, not observational errors, but rather the peculiar velocities of spirals.

From the foregoing result we infer that one way of accounting for the observed increase of average V_r with distance from the so-called galactic apex is by assuming that the galactic system moves toward longitude 105°, approximately, with a velocity of some three hundred kilometers a second, while the spirals of the brightness here involved recede with an average systematic radial velocity of six or seven hundred kilometers a second.[1]

6. If we should assume that the average systematic motion is perpendicular to the galactic plane rather than radial from the center of the galactic system, or radial from the sun as is observed and assumed above, then we would have for this perpendicular velocity

$$V_p=(V_r-V_g\cos\theta)\operatorname{cosec}\beta$$

and a solution of the four mean observational equations derivable from (2) gives, provisionally,

$$V_p=+775\text{ km/sec.},\quad V_g=+140\text{ km/sec.}$$

The least-squares solution of the 23 conditional equations then leads to the following results:

$$\begin{aligned}V_p&=+765\pm\ \ 55\text{ km/sec.}\\V_g&=+110\pm100\text{ km/sec.}\end{aligned}$$

and the average value of O−C is ±250 km/sec. The probable errors give little choice between assumptions involving radial and perpendicular systematic motion, but the conception of radial motion is distinctly preferable from the standpoint of physical probability.

When sufficient data become available, not only should V_g and V_s (or V_p) enter the computations, but also the co-ordinates of the origin of θ.

[1] Following the procedure commonly used to determine the apex of the solar motion, Truman, Young and Harper, and Slipher have computed from the radial velocities of spirals a motion of the galactic system toward a rather vaguely defined southern apex; but they have assumed, explicitly, a random peculiar motion for spiral nebulae and, implicitly, the "island universe" hypothesis. Their result is an obvious consequence of the preferential recession and of the absence of spirals of known velocity from the southern sky.

7. From the present evidence we see that there is a magnitude effect for the very brightest objects; in addition the observed velocities of spirals may be divided into three parts, the first two of which appear to be very definite: (*a*) a systematic radial recession of more than 600 km/sec., which is increased by one-sixth if the systematic motion is assumed to be perpendicular to the galactic plane; (*b*) the peculiar velocities, which average about ± 250 km and are represented by the deviations from the means and formulae; (*c*) a component of the radial velocity whose effect decreases on the average with distance from the "galactic apex," and which may be interpreted as a drift of the whole galactic system with respect to the brighter spiral nebulae. This last component is the least definite, quantitatively, but on the other hand we shall see that its existence seems to be affirmed by the distribution of spirals and by other considerations discussed in the last part of Section VIII.

The apparent distribution of spiral nebulae appears to be sufficiently known for a general statement, though much remains to be done in extending the recent work of Hardcastle, Fath, Sanford, and Curtis. That the spirals approach nearest to the Milky Way in two hours of right ascension ($\omega = 100°$) has been noted by Hinks, Stratonoff, and others. Globular clusters are wholly absent from that region, and it is very significant that in the opposite region of the sky, where globular clusters and clouds of stars most abound, the avoidance of the Milky Way by spirals reaches its maximum.[1]

Thus the region avoided, at least by the brighter spirals, is roughly defined by a wedge, symmetrical in relation to the galactic plane, with its base in the general direction now adopted as the center of the galactic system. A wedge-shaped arrangement (analogous to the wedge-shaped avoidance by spirals) has been pointed out for globular clusters in Section III of this paper, but the base of the wedge lies in a direction approximately opposite to the direction of the center.

[1] See the diagrams by Hardcastle and Hinks (*Monthly Notices*, **74**, 699, 1914) and the bibliography and discussion by Sanford (*Lick Observatory Bulletins*, **9**, 82, 1917).

There is, accordingly, in the contrasted distribution of spirals and globular clusters, as well as in the opposing directions of their motions, an indication that the compelling forces act in opposite directions.

VIII. DATA AND INFERENCES FOR A PROVISIONAL COSMOGONY

The observational results discussed in the foregoing sections of the present contribution and in the thirteen preceding papers of this series permit the statement of five of the conditions that must be considered in attempting to account for the origin of the galactic system and its present relation to clusters and spiral nebulae: (1) the similarity of globular clusters in dimensions and content; (2) the complementary distribution of open and globular clusters; (3) the existence of thousands of suborganizations in the galactic system; (4) the contrasted distribution of spiral nebulae and globular clusters; and (5) the opposed directions of preferential radial motion for spirals and clusters.

In the following paragraphs we offer a brief summary of the observational data bearing on each of these five conditions and a suggestion as to the general interpretation of the evidence.

1. The parallax-diameter curves in *Mount Wilson Contributions*, No. 152 and in Section V of this paper indicate that with few exceptions globular clusters have approximately the same linear diameters. Observations of (*a*) the integrated light of clusters, (*b*) their general luminosity-curves, and (*c*) the phenomena of color and absolute magnitude of their giant stars show also that the stellar content is much the same from system to system.

2. For globular clusters the frequency-curve of galactic latitudes has a distinct minimum at the galactic plane, whereas the corresponding curve for open clusters shows a pronounced maximum in low latitudes (Figs. 1 and 2 of this paper). The evidence suggests that the two kinds of clusters occupy regions of space that are mutually exclusive (Sections I and III of this paper). There is some indication that a transition from one kind to the other occurs along the outskirts of the equatorial galactic segment.

3. Numerous conditions suggest that the Galaxy is a heterogeneous assemblage of unequally organized parts. The remarkably

wide pairs of stars of common motion, the local moving groups, the open clusters, the clouds of the Milky Way, the star-streams[1]—all these combinations indicate that the galactic system may be largely composed of disintegrating clusters. The testimony of the distribution and radial motion of globular clusters indirectly supports this view, and suggests further that the system is now growing and has gradually grown throughout the past from a much less complicated state.

4. While both globular clusters and spiral nebulae appear to be mainly if not wholly outside the equatorial galactic segment, they occur in general in different parts of the sky. In the Southern Hemisphere the globular clusters crowd in close to the Milky Way and the bright spirals widely avoid it; in the Northern Hemisphere the spirals approach their nearest to the galactic circle and globular clusters are almost wholly absent.[2]

5. Globular clusters as a class appear to be rapidly approaching the galactic system; spiral nebulae as a class are receding with high velocities. The relation of the velocities of spirals to brightness and to position in the sky has been dealt with above in Section VII. Some of the reasons for not considering spiral nebulae to be separate galactic systems have been outlined in the introduction to the twelfth paper of this series. For the present we shall accept that the distances of globular clusters and spirals are of the same order, and that, with the possible exception of a few of the very brightest, none is within mid-galactic stellar regions.

The foregoing conditions, when considered in connection with previously accepted stellar and nebular results, suggest as a preliminary hypothesis that the discoidal galactic system originated

[1] Accepting the evidence presented in *Mt. Wilson Contr.* No. 157 (see also the ninth section of this contribution) bearing on the existence of a local cluster, we note that from material now available the circum-solar cluster appears to be both larger and more oblate than typical open or globular systems; it seems to be more like the Magellanic Clouds in dimensions. Possibly before it became a member of the galactic system it represented the discoidal combination of several smaller clusters, the residual nuclei of which are still shown in the Orion, Perseus, and Scorpio-Centaurus groups of B stars.

[2] See the last three paragraphs of Section VII of this paper.

from the combination of spheroidal star clusters and has long been growing into its present enormous size at their expense. The evidence further suggests that the galactic system now moves as a whole through space, driving the spiral nebulae before it and absorbing and disintegrating isolated stellar groups. Apparently the suggested interpretation requires that two types of sidereal organization prevail generally throughout extra-galactic space: spiral nebulae, and stars of known types assembled for the most part into globular clusters;[1] and while the globular clusters now known are, at least potentially, members of the galactic system, the spirals are not members, rather being general inhabitants of extra-galactic space. The hypothesis demands that gravitation be the ruling power of stars and star clusters,[2] and that a repulsive force, radiation pressure or an equivalent, predominate in the resultant behavior of spiral nebulae.

[1] The apparent limitation of the size and mass of a globular cluster (the first of the five conditions) suggests, for example, the narrow range in masses of stars, for which the limiting factor, according to Eddington's theory, is the balance of attractive and dispersive forces. Judging by the galactic system, and perhaps by the local cluster and the Magellanic Clouds, the discoidal form permits a greater mass; and if, as seems likely, the Magellanic Clouds recently passed through the galactic system (cf. p. 12, n. 1, of the twelfth paper) a stellar discoid possibly shows much greater stability than is possessed by the compact spheroidal distribution.

[2] Jeans has considered mathematically the effect of the encounter of two clusters, showing the transformation from the globular to the oblate form (*Monthly Notices*, **76**, 552, 1916). His analysis may direct the way to an understanding of the beginning of a flattened stellar system of growing mass.

If such a growth be theoretically possible, we may suppose that at first the combination of separate clusters would proceed very slowly to the formation of composite systems of increasing mass, the galactic system that finally results representing an advanced stage in the survival of the most massive and stable. Once an enormous mass had been acquired, subsequent accretions would be numerous and almost inevitable if ordinary unit spheroidal clusters were encountered rather than growing discoids of multiple mass. The distinctly limited galactic star clouds, some of which are not mid-galactic, and the rapidly receding Magellanic Clouds as well, might represent partially assimilated and controlled systems of greater mass. Undoubtedly some globular clusters would merely describe orbits around the growing Galaxy and outside the limits of the system would cross the galactic plane, but our observations do not show them; it may be the true "orbital" clusters are constrained to keep far from the galactic system, all near approaches ending in disorganization. (Compare the tentative hypothesis sketched in the seventh section of *Mt. Wilson Contr.* No. 147, 1918.)

Relative to spiral nebulae, two additional conditions that seem not to have been considered heretofore may be pointed out as significant in connection with the proposed hypothesis.

a) In the midst of a field of stars the effect of repulsive forces would be largely nullified by the symmetrical distribution of the sources of repulsion (assumed to be the stars); above or below a discoidal stellar field the action is of course wholly one-sided.

b) The extremely high velocities of recession indicate that, if the galactic system had remained stationary, most of the brighter spirals would have been among the stars in low galactic latitudes within recent cosmic times, for instance within the last twenty million years. That scarcely any spiral (on either side of the galactic plane) is approaching or is now among the stars in low galactic latitudes not only suggests that a repulsive force is predominant, but also indicates either (1) a movement of the entire Galaxy through space, or (2) recently accelerated motions of spirals, or (3) distances enormously greater than now seem at all probable.

The last supposition, though extending the time allotted, would not remove the difficulty of accounting for the absence of spirals from the equatorial segment at the present time. For example, four bright spirals in high galactic latitude are receding with a velocity in excess of 1/300 that of light. Suppose they are as much as two million light-years away—ten times the distance of the remotest globular cluster known. Then, with constant velocities throughout the past, they would have been at the galactic plane less than 600 million years ago—an interval of time so short in the life-history of a stellar system that in the case of the sun, for instance, it has not sufficed to show an appreciable change in radiation.[1]

It is more in keeping, however, with observations of apparent rotation, and with the luminosity of novae in spirals, to divide by one hundred the distance supposed above. Only a few million years are therefore involved in the problem, and it seems all the more necessary to accept, in view of the observed distribution and radial motion, either (1) that the Galaxy is moving or (2) that the velocities have been rapidly developed. The suggestion (2) that

[1] *Publications of the Astronomical Society of the Pacific*, **30**, 283, 1918.

the position of the Galaxy has remained stationary while the velocities of spirals have but recently become large does not commend itself for various reasons, including the consequent necessity of seeking the origin of spirals in the galactic regions where now they are not observed.

The remarkable progression of average velocity with distance from the "galactic apex," discussed in Section VII of this paper, is also simply explained by assuming that the galactic system moves in the direction and with the velocity required by these phenomena of distribution and motion. We conclude, therefore, that the most plausible interpretation of the present arrangement and motions of the brighter spirals implies repulsion by the moving discoidal galactic system;[1] but we keep in mind the alternative hypotheses.

IX. NOTE RELATIVE TO THE MORE DISTANT B STARS OF THE LOCAL SYSTEM

The stars of spectral type B, because of their relatively small dispersion in absolute magnitude and their tendency to clustering and to community motion, are particularly valuable in studying the form and position of the local star cluster whose existence and general properties have been discussed provisionally in the last part of

[1] Is it possible that the spirals represent the failure to form stars from the original condensing nebulosity through the presence of too much material? According to Eddington's theory of the structure of a giant star (*Monthly Notices*, 77, 16, 596, 1917), the pressure of radiation nearly counterbalances gravitation if the condensing gaseous mass exceeds some 10^{35} grams. A mass 100 times that of the sun would incompletely condense, possibly with the result of a diffuse pseudo-stellar nucleus, grading off into the extensive, low-density envelopes of gas that are unable to fall into the center because of the balance of radiation. Such a body would not readily disintegrate (since the ratio of radiation pressure to gravitation cannot exceed unity), but would present to external repulsive forces a surface relatively large for the mass involved, and composed, it may be, of particles of molecular dimensions peculiarly susceptible to the pressure of such radiation as is emitted by the stars. The existence of powerful electrical fields in spiral nebulae would clarify the problem, and already Slipher has suggested (*Lowell Observatory Bulletin*, No. 80, 1917) that such may occur in Messier 77 and Messier 1. Spirals of greatest mass or density would be least repelled by the galactic system, and if their individual velocities directed them toward a radiant source they might not be easily turned aside. In his study of the rôle of rotation in cosmogony Jeans has shown the probable development of spiral arms when the condensing body greatly exceeds the sun in mass (*Monthly Notices*, 77, 186, 1917; *Scientia*, 24, 270, 1918).

the twelfth paper of this series. Although the overwhelming majority of brighter B stars treated in *Mount Wilson Contributions*, No. 157 belong to the cluster, a few appear from the evidence of space positions to be field stars, in corroboration of Kapteyn's result that occasionally B stars are found in the second stream.[1]

It has frequently been assumed, mainly on the basis of an extrapolation, that all B-type stars are included in the earlier catalogues of spectra—that fainter than the seventh or eighth visual magnitude no stars of that class of spectrum would be found. Such a condition would place a sharp limit to the extent of the local cluster, assuming it to be outlined by stars of type B. Extremely faint and distant blue stars, however, have been found in the galac-

[1] The complete identification of the local cluster with Stream I involves some difficulties that were not sufficiently appreciated when the earlier paper was written. The two most important obstacles in the way of the suggested interpretation, which made star-streaming simply the result of uniform motion of the local cluster through the galactic field, appear to be the high relative velocity of the two streams and the probably different stream velocities for different spectral types. There seems to be no doubt of the existence of a definitely organized local cluster, and it certainly contains practically all of the brighter B stars. Kapteyn's studies also leave little doubt that the B stars as a whole, and therefore this cluster, move toward an apex approximately the same as the apex of the first stream as determined from stars of other types. The moving cluster must give rise to a true stream-motion. It happens that the position of the sun with respect to the local cluster's center (the direction of which is shown by F-G-K stars as well as by the B's) is such that we may have, in addition to and hardly distinguishable in direction from the true stream-motion, a pseudo-stream-motion due to internal circulation (according to Strömberg's suggestion, for instance).

These two possible sources of the observed preferential drift of stars were recognized from the first, but in the provisional discussion the internal motion was considered relatively of minor importance. Now it appears that the two difficulties mentioned above, and other minor ones, may be avoided if necessary by inverting the relative importance of the two sources of stream-motion. The cluster accordingly contains not only all the stars of Stream I but a considerable part of those of Stream II, and the cluster's direction and speed of motion are best measured by the mean drift of the early B stars. The average internal velocity may of course vary with spectral type without disrupting the cluster. Professor Eddington suggests in a letter that the field should probably be identified with Halm's O-stream, which contains a great many second-type stars formerly assigned to the first and second streams.

The modified view sacrifices little of the simplicity of the former statement and at the same time uses in a rational manner the large local cluster, whose existence must play an important part in the problem of star-streaming. Except in this matter of motion and content, none of the earlier conclusions referring to the local cluster appears to require appreciable modification.

tic clouds far beyond the limits of the local cluster, and the data given below show that Class B is also represented in considerable numbers among stars from the seventh to the tenth apparent magnitude.

The first volume of the *Henry Draper Catalogue*,[1] which covers the first four hours of right ascension, contains nearly 26,000 stars, of which 832 belong to Class B. It contains 600 B stars fainter than the seventh magnitude, corresponding to about 3 per cent of the total for all types. For the naked-eye stars over the whole sky the percentage is of course much larger, and, because of the galactic concentration of B stars, it will likely be larger also for the faint stars in those instalments of the new catalogue that include larger portions of the Milky Way. Practically all the B stars of this first volume are in Cassiopeia and Perseus.

Stars of the subdivisions B8 and B9 are generally discussed in connection with A-type stars. In the present note we shall only call attention to the following tabulation of the total number of such stars brighter than successive half-magnitude limits:

Visual magnitude	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
Total No. stars	7	17	32	56	95	156	235	317	430	537:	591::
Ratio		4.6	3.3	3.0	2.8	2.5	2.0	1.8	1.7:	1.4:	

The ratio N_{m+1}/N_m in the last line shows the decrease of density with distance.

The numbers of stars in the first five divisions of Class B are shown for different intervals of visual magnitude in Table VII. The limit to which the catalogue is complete is not specifically stated, but is probably in the neighborhood of visual magnitude 8.5. The 38 B stars with undetermined subdivision are more likely to belong in this table than with the stars of types B8 and B9.

Evidence discussed below indicates that the mean absolute magnitudes may be accepted as the same for all these faint stars as for the brighter B's, whose motions and parallaxes have led to the evaluation of their average intrinsic luminosities. Table VII indicates, therefore, that B stars are found continuously to a distance of possibly 1000 parsecs in the direction of Perseus and Cassiopeia.

[1] *Harvard Annals*, **91**, 1918.

TABLE VII

NUMBERS OF B-TYPE STARS IN *Harvard Annals*, 91

Spectral Type	Visual Magnitude							Total
	<7.0	7.0–7.5	7.5–8.0	8.0–8.5	8.5–9.0	9.0–9.5	>9.5	
B0	6	3	2	2	3	2	0	18
B1	4	2	1	0	1	0	0	8
B2	7	1	5	5	7	0	0	25
B3	26	11	7	5	7	1	2	59
B5	35	9	5	11	4	2	3	69
B0–B5	78	26	20	23	22	5	5	179
Undefined B	0	0	4	12	8	10	4	

Table VIII affords evidence that the 101 stars fainter than the seventh magnitude and of spectral types B0–B5 are possibly in large part members of the local cluster. The galactic latitudes, derived graphically from charts prepared by Kapteyn, are tabulated in order of decreasing brightness, the horizontal lines in each column marking the magnitude intervals of Table VII. All stars in the table are north of the celestial equator except the eight with galactic latitudes in excess of 41°.

With respect to the galactic plane, the descending node of the central plane of the local cluster is in galactic longitude 70°, approximately, as is clearly shown by Fig. 4 of *Mount Wilson Contributions*, No. 157. The galactic longitudes of the stars involved in Table VIII are almost exclusively between 85° and 130°, and, therefore, if they belong to the cluster rather than to the general galactic field, their latitudes should be predominantly negative. This is seen to be the case, and in fact we are led to believe that most stars of types B0, B1, B2, brighter than the tenth magnitude, may be members of the local system.

The area of the sky between right ascension 0^h and 4^h is mainly in the southern galactic hemisphere. Hence, for a fair comparison of the number of stars in positive and negative galactic latitudes, we should consider only a narrow belt along the galactic circle—the region within $\beta \leqq 5°$, for instance. We have then the following indication that the distribution of the early B-type stars of Table VIII may have little or nothing to do with the galactic

TABLE VIII

GALACTIC LATITUDES OF B-TYPE STARS FAINTER THAN MAGNITUDE 7

Bo	B1	B2	B3		B5	
+8°	−4°	+ 2°	− 3°	0°	− 8°	− 6°
+8	−3	− 3	− 4	+ 4	+ 2	+ 7
+1	−4	−12	+10	− 2	− 5	− 4
+6	−4	+ 1	−21	− 2	− 5	− 4
−2		− 5	−50	− 2	−12	− 6
−4		− 6	− 3	− 3	−23	+ 2
−4		− 2	− 2	− 5	−82	+ 4
−2		− 3	− 2	−42	− 3	+ 5
−4		−12	− 1	− 5	+ 1	− 5
−3		− 5	− 9	− 2	−12	−64
−4		− 5	−15	− 4	−16	− 6
−2		− 4	+ 2	− 5	+ 6	− 4
		− 3	+ 2	− 4	− 4	−63
		−19	+ 6	− 4	− 5	− 5
		− 4	− 3	− 6	−46	−54
		− 4	−54		− 7	− 6
		− 5	−16		+ 1	
		− 5	+ 2		+ 2	

plane—rather, these stars appear to be condensed to a circle that in this region of the sky is three or four degrees south of the galactic circle:

Spectrum		Bo	B1	B2	B3	B5	Bo–B5
Number of stars	β negative	8	4	12	18	10	52
	β positive	1	0	2	4	7	14

The maximum frequency of the galactic latitudes for the 101 faint stars of types Bo–B5 is about $-4°$ according to the following tabulation, which is based on Table VIII:

β	$\geqq +10°$	$+9°,+8°$	$+7°,+6°$	$+5°,+4°$	$+3°,+2°$	$+1, 0°$	$-1°,-2°$
No. of stars	1	2	4	3	7	5	11
β	$-3°,-4°$	$-5°,-6°$	$-7°,-8°$	$-9°,-10°$	$-11°,-12°$	$-13°,-14°$	$<-14°$
No. of stars	28	19	2	1	4	0	14

It is easy to show that the dip of the equatorial circle of the cluster, due to the sun's position to the north of its central plane, is less than $-1°$ for stars at the mean distance of those concerned above.

Allowing for the dip, and assuming that in the mean these B-type stars are about 25° from the descending node, we may make a rough determination of the angle between the central plane of

the local cluster and that of the Galaxy. The result is 8°, in fair agreement with the earlier value of 12°, but naturally of much lower weight. Accordingly, we may conclude, as previously assumed, that the existence and inclination of the local cluster do not depend upon the accidental positions of a few groups of brighter B stars.

The most significant feature of the preceding tabulation, however, is the high concentration to the central plane. More than half of all these stars fall into the interval of latitude −2° to −6°, and three-fourths of the B0, B1, B2 stars are within those limits. For B-type stars brighter than those considered here the dispersion is decidedly greater, both in this part of the sky and in general.

Three interesting conclusions may be drawn from the foregoing result: (1) The failure to find the fainter B stars heretofore may be due to the extremely narrow belts within which they are to be found—one belt, moreover, apparently standing well out of the lowest galactic latitudes for regions of small declination. (2) The local cluster is exceedingly flat, at least as far as the B-type stars are concerned. It may be more than five times as extended in its plane as at right angles. Table VIII shows how infrequent are the faint B stars in high galactic latitudes. (3) The greatly increased concentration for the fainter stars may be taken as proof that these objects, rather than peculiar B stars of abnormally low intrinsic brightness, are normal stars at a greater distance from the sun.

The completion of the *Henry Draper Catalogue* will afford a good basis for testing and extending the results outlined above.[1] With data for the whole sky we shall be able to define more accurately the position of the local cluster in the galactic system and perhaps determine its form completely.

MOUNT WILSON SOLAR OBSERVATORY
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[1] *Note added to proof:* Data derived from the second instalment of the *Henry Draper Catalogue* fully verify the existence of a secondary Galaxy as outlined by early B-type stars. The faintest B's, however, show a decided preference for the primary Galaxy, in contrast to the stars discussed above. Possibly a branching of the main Milky Way stream in Perseus and Cassiopeia, or the wide extent of the open clusters in Perseus, is largely responsible for the great preponderance of negative latitudes in the foregoing discussion; and accordingly these faint B's may be only in part members of the local cluster.